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Distributed Generation unit and Capacitor Placement for Multi-objective Optimization

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ABSTRACT

Distributed Generation (DG) and capacitors placement and the tap setting of ULTC transformers can be used individually to reduce loss, improve the voltage profile and increase the available transfer capability (ATC) of the distribution network. Simultaneously placement and setting of these devices will be more effective. In this paper, this method is implemented by multi-objective function. The objective function consist the loss reduction, voltage improvement and increasing ATC. Genetic Algorithm (GA) methodology is used to optimize the objective function. To show the effectiveness of the proposed method, it is applied to IEEE 41 bus radial distribution network. The results show that this method has a better effect on improving the objective functions

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1. INTRODUCTION

DG and capacitor placement are nonlinear optimization problems with many variables and equality and inequality constraints. There are many methods for DG and capacitor placement for different purposes. A distribution network operation can be improved by adding DG and capacitor. In addition, it can appropriately be controlled with existing equipments, such as ULTC setting. The previous studies in this field can be categorized into three parts:

1.1 Capacitor Placement

Historically, improving the distribution networks at first initialized with the placement and the appropriate size of capacitor selection. Many studies on capacitor placement have been done. The recent works in this case are as follows: Determining the place and the size of capacitor banks in distorted distribution systems is discussed and genetically optimized-fuzzy is used for optimization in [1]. The objective function is referred to reduce loss, optimize power and capacitors placement’s cost, considering load voltage constraints and THD. Capacitor placement and reconfiguration problem for loss reduction of distribution networks are solved in [2] by an ant colony search algorithm. In addition, a heuristic constructive algorithm for capacitor placement in distribution systems is applied in [3].

1.2 DG Placement

In recent decades, different kinds of DGs have been made and different methods have been introduced for DG placement. In [4], a method for placement of a single DG in distribution network has been proposed. This method is based on the determination of most sensitive buses with voltage collapse. The analysis was carried out to reduce losses, improve the voltage profile, and increase ATC. In [5] a multi-objective optimization method for DG placement has been associated. One of the main factors in that paper is to reduce the network loss. A heuristic DG optimization method for distribution network is proposed in [6] and the search space is reduced significantly. In [7] a method to select the load buses for DG placement based on loss reduction and voltage improvement sensitivity of the system has been presented. An analytical approach for optimal placement of distributed generation sources in power systems are aimed to reduce power loss using analytical methods in [8].

1.3. Simultaneous DG and Capacitor Placement

Nowadays different kinds of DGs and capacitors are simultaneously used in many distribution networks. In [9] placement of DG and capacitors to reduce losses and improve the voltage profile using GA has been studied. In addition, two optimization models are proposed to improve the voltage profile. First, the DG placement problem is formulated and then the capacitor placement problem is modelled and solved in [10].

This paper proposes the simultaneous placement of capacitors, DG and also tap setting. The proposed multi-objective function contains loss reduction, voltage profiles improvement and ATC increase. This objective is limited with voltage magnitude at each bus and passing apparent power through at each line. It should be mentioned that, other articles have less attention made to DG and capacitor placement with tap settings of ULTC simultaneously. The IEEE 41 bus radial distribution network, which can be found in [10], is used to illustrate the effectiveness and feasibility of the proposed method. Simulation results show that the simultaneous determining of the location and size of DG and capacitor and the tap setting of ULTC transformer give more favourable results. The results show that the voltages in all buses remained within the desired range, loss reduced and ATC increased.

2. RESEARCH METHOD

The problem, which is formulated through a multi-objective function is described below.

2.1 Reducing power losses

In the power distribution network, loss depends on two factors, line resistance and line current. Variations of the line resistance are low and negligible. Overall line loss is related to the current and the line current depends on system topology and loads. It is usually impossible to reduce the value of the load, but line currents can be reduced with DG and capacitor proper placement. Therefore, with optimal DG and capacitor placement, line loss can be decreased. The power flow equation can be formulated as:

$$P_i = V_i \sum_{j=1}^{n} Y_{ij} V_j \cos(\delta_i - \delta_j - \gamma_{ij}) \tag{1}$$

$$Q_i = V_i \sum_{j=1}^{n} Y_{ij} V_j \sin(\delta_i - \delta_j - \gamma_{ij}) \tag{2}$$

where, P_i and Q_i are active and reactive power of the i'th bus respectively, V_i is the i'th bus voltage, and Y_{ij} is the admittance between bus i and j., δ is the bus voltage angle, and γ is the angle of the system admittance matrix element. The first objective function (f_1) can be defined as:

$$f_1 = P_{loss} = \sum_{i=1}^{n} P_{G_i} - \sum_{i=1}^{n} P_{D_i} \tag{3}$$

This objective function shows the total line loss in the entire system (P_{loss}). P_{Gi} is the injected active power from power system to distribution network or i'th bus generated power by i'th DG. P_{Di} represents the total connected load.

2.2 Voltage improvement function

It is obvious that the voltage of each buses should satisfy the following constraint:

$$V_i^{min} \le V_i \le V_i^{max} \qquad i = 1,2,\dots,N_b \tag{4}$$

where N_b stands for the total number of buses. V_i , V_i^{min} and V_i^{max} are i'th bus voltage magnitude, lower and upper boundaries of voltage magnitude of i'th bus respectively. The second objective function can be proposed to decrease the difference between the voltage magnitude of busses and their nominal value. This function is formulated as:

$$f_2 = \sum_{i=1}^{N_b} (V_i - V_n)^2 \tag{5}$$

where V_n is the nominal voltage value, which is considered one p.u. for all the buses in this article.

2.3 ATC increment function

ATC is one of the important factors in DG and capacitor placement in distribution networks. The capability of transmission lines is limited by ATC in the distribution network. DG and capacitor placement appropriately increase the ATC, because they inject active and reactive power in the distribution network. The third objective function (f_3) is proposed to increase the available transfer capability that is defined as (6).

$$f_3 = \sum_{i=1}^{n}(S_{base} - S_{i-j}) \quad (6)$$

$$S_{i-j} = \sqrt{P_{i-j}^2 + Q_{i-j}^2} \quad (7)$$

$$S_{base} = S_{1-2} \quad (8)$$

Where, S_{i-j} is the value of apparent power flow from i'th bus to j'th bus. S_{base} is the Total Transfer Capability (TTC), which is equal to S_{1-2} when there is no DG and capacitors placement and ULTC voltage ratio is set to one. The value of S_{1-2} is determined as illustrated in results and analysis section. Bus 1 is considered to be connected to a substation bus. P_{i-j} and Q_{i-j} are the value of active and reactive power flow from i'th bus to j'th bus.

2.4 Multi-objective function

GAs can make possible simultaneous convergences to more than one optimum solution in a multimodal search. It is possible to adapt the genetic algorithm for determination of the global or near global optimum solution [11]. In this article, GA is applied to DG and capacitors placement and tap settings of ULTC. In addition, GA is used to determine active and reactive power values of DG and capacitors. By proper choice of all variables using GA, multi-objective function is optimized. In this paper, the multi-objective function is described as:

$$F = f_1 + f_2 - f_3 \quad (9)$$

Where, F, f_1, f_2 and f_3 are multi-objective function, loss reduction, load voltage profiles optimization and ATC maximization, respectively.

f_1 and f_2 should be minimized while f_3 should be maximized.

3. RESULTS AND ANALYSIS

The proposed method is applied to the IEEE 41 bus radial distribution network. The structure and parameters of the system are presented in [10]. Bus 1 is a substation bus and distribution network has one ULTC transformer at the first bus. This network has 41 load buses and 40 section lines. Total active and reactive loads are 4.635 MW and 3.250 MVar, respectively.

TABLE I
DG and Capacitor Characteristics

	Number	Max. Active Power (MW)	Max. Reactive Power (MVar)
DG	1	4.0	2.0
Capacitor	4	-	0.4

TABLE II
ULTC characteristics

	Tap Numbers	Min. (V_i /V_o)	Max. (V_i /V_o)
ULTC	6	1.00	1.05

In this paper, one DG and four capacitors are placed in the network. DG, capacitor and ULTC characteristics are as shown in Table I and II, respectively. In the first stage, load flow was performed on the IEEE 41 bus distribution network. The voltage conversion ratio of the ULTC is set to one in this simulation.

Power consumptions in distribution network are supplied only by the power system. At this stage the distribution network does not contain any DG and capacitor. Numerical results of three objective functions are shown in Table III.

In Table III, the network has relatively high losses and load bus voltages are not desirable. In addition, a high power passes through the first line of the network, which is equal to 6.9860 MVA, that is considered as the S_{base} Value in Equation (6).Therefore, active and reactive power generators are needed to improve the overall network status.

The second, third and fourth simulation steps are made based on adding a DG and four capacitors in the network. The GA attempts to minimize the values of f_1 and f_2 and maximize f_3. In the second simulation, only the loss reduction is considered, and the effort has not been made to improve both the bus voltage profile and increasing the ATC. The numerical results of this stage are summarized in Tables IV.

In the third simulation, only the voltage profile is improved and the results are reported in table V. The fourth study is based on increasing the ATC and its relative results are shown in table VI.

Main objective functions of each stage are highlighted in gray colour in Tables IV, V and VI. By comparing these results, it is clear that in Table IV, losses are lower but bus voltage profiles are undesirable. Conversely, in Table V, losses are higher and bus voltage profiles are more favourable. By adding DG and capacitors and comparing Table VI with two previous tables, it can be seen that ATC is improved. The comparison of the apparent power flow between bus 1 and 2 (S_{1-2}) in all tables with Table III shows that line current in the distribution network with DG and capacitors is significantly reduced. According to the mentioned results, using a mono-objective function cannot improve the network performance.

TABLE III
Numerical results of three objective functions without DG and capacitor

Variable	Value
f_1	1.0075
f_2	1.8238
f_3	228.7923
$S_{1\text{-}2\ MVA}$	6.9860
$V_{trans\text{-}pu}$	1.00

TABLE IV
Numerical results of three objective functions with loss reduction function

F = f1	
F	0.1114
f_1	0.1114
f_2	0.0575
f_3	259.9215
$S_{1\text{-}2\ MVA}$	2.386
$V_{trans\text{-}pu}$	1.05
$P_{DG\ MW}$	2.4
$Q_{DG\ Mvar}$	1.3
DG_{Place}	bus 10
$C_{1\ Place}$	bus 27
$C_{2\ Place}$	bus 29
$C_{3\ Place}$	bus 31
$C_{4\ Place}$	bus 38

TABLE V
Numerical results of three objective functions with improving voltage profiles function

F = f2	
F	0.0057
f_1	0.1678
f_2	0.0057
f_3	258.4299
$S_{1\text{-}2\ MVA}$	1.556
$V_{trans\text{-}pu}$	1.01
$P_{DG\ MW}$	3.4
$Q_{DG\ Mvar}$	1.1
DG_{Place}	bus 9
$C_{1\ Place}$	bus 30
$C_{2\ Place}$	bus 32
$C_{3\ Place}$	bus 33
$C_{4\ Place}$	bus 41

Considering the optimized numerical values, the differences between three mono-objective function values are considerable. Therefore, per unit system is required for multi-objective optimization problem. In this regard, the results of each individual optimization in second, third, and fourth stages are used as the base values of f_1, f_2 and f_3.The base values are as follows:

$$f_{1\text{-}base} = 0.1114 \tag{10}$$
$$f_{2\text{-}base} = 0.0057 \tag{11}$$
$$f_{3\text{-}base} = 261.4437 \tag{12}$$

Finally, the multi-objective function is built using a combination of three mono-objective functions. The simulation results are presented in Table VII, which are normalised based on the base values of Equations (10) to (12). By comparing the gray cells of Table IV to Table VII, it can be shown that using the multi-objective function, each of the three functions are improved to acceptable values.

TABLE VI
Numerical values of three objective functions with increasing ATC function

	$F = f3$
F	261.4437
f_1	0.1335
f_2	0.0152
f_3	261.4437
$S_{1\text{-}2\,MVA}$	1.870
$V_{trans\text{-}pu}$	1.03
$P_{DG\,MW}$	3.1
$Q_{DG\,Mvar}$	0.9
$DG_{\,Place}$	bus 9
$C_{1\,Place}$	bus 30
$C_{2\,Place}$	bus 31
$C_{3\,Place}$	bus 38
$C_{4\,Place}$	bus 39

TABLE VII
Per unit values of three objective functions with multi-objective function

	$F_{pu} = f_{1pu}+ f_{2pu} - f_{3pu}$
F	1.2932 p.u.
f_1	1.2184 p.u.
f_2	1.0675 p.u.
f_3	0.9927 p.u.
$S_{1\text{-}2\,MVA}$	2.468
$V_{trans\text{-}pu}$	1.02
$P_{DG\,MW}$	2.4
$Q_{DG\,MVar}$	1.0
$DG_{\,Place}$	bus 10
$C_{1\,Place}$	bus 30
$C_{2\,Place}$	bus 31
$C_{3\,Place}$	bus 33
$C_{4\,Place}$	bus 40

In other words, by using an intelligent optimization algorithm with a multi-objective function, it is possible to improve the overall network performance. Figure 1 shows the results of bus voltage magnitudes using the proposed method. It shows that, voltage magnitudes in all the buses are favourable.

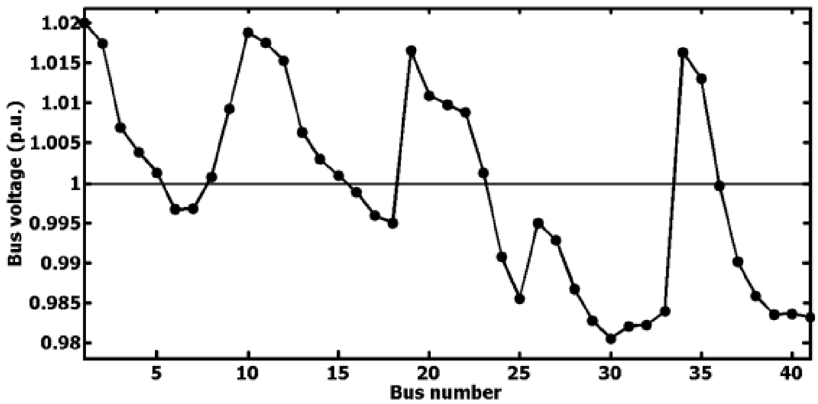

Figure 1. Bus voltage magnitudes using the proposed method

4. CONCLUSION

In this paper, an improved GA based method for proper placement of a DG and capacitors plus the tap setting of ULTC transformers are proposed. The proposed algorithm is based on a new multi-objective function, which is matched with three mono-objective functions to reduce losses, improve the bus voltage profiles and to increase ATC. To verify the proposed method, simulations are carried out on the IEEE 41 bus distribution network. The capability of this method is well shown by the results. The simulation results using multi-objective function has validated the effectiveness of the proposed approach.

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